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Art. XIV.—*The Increasing Run-off from the Avoca River Basin (due apparently to Deforestation).*

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(With one Text fig.)

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Some consideration has been given to this in a previous paper dealing with the Control of Climate by Human Agency. This, however, was very casual and depended mainly upon the writer's impressions, which are based upon recollections going as far back as 1870.

The chief points of interest are:—

1. The flooding of the river,
2. The duration of the flow each year,
3. The minimum flow each month,
4. The actual run-off.

These are obviously influenced by the changes wrought through our occupation of the drainage areas of the river, which dates back only for about 60 years. Such pastoral use as had been made of it for a few years previously was probably negligible in its effects.

Physiographic Changes.

The recent changes in the stream beds, which appear to have begun about 1880, have been most striking. Up till about that time large waterholes, many of which were 20 to 40 yards long, 10 to 15 yards wide, and 8 to 10 feet deep, were a feature of the streams, and occurred at very short intervals, usually of only a chain or two. The channels connecting these were almost always very shallow. One old resident of Amphitheatre, a lady, testified that she was able, in 1861, to step across the Avoca River, or Glenlogie Creek anywhere. For the next 30 years, or until the early 'nineties, the changes in the channels of the Avoca River, above the town of Avoca, and in its tributaries generally, were not particularly noticeable, but during the last decade or two have become very marked. The destruction by stock of the reeds and coarse grasses lining the channel, and the removal of logs and growing trees, have permitted the beginning of erosion, and this has lately become rapid. The effect is a double one. The aquatic grasses which often covered the beds of the smaller streams, and the coarse grasses and trees which lined the beds being destroyed, the cutting of the channel began. This gradually lowered the level of the water in the water holes, and now in most cases has almost completely drained them. When the flow is rapid, a fairly deep and

uniform channel is eroded, but so far I have seen no serious lateral erosion. The rich, black soil flats are being deeply scored, but there has not been any great loss of area, although the deposition of masses of gravel and shingle in talus or delta fashion, where the streams emerge from the hills, or reach flatter country is damaging many rich pastures. Fords are difficult to maintain, and much bridge building is becoming necessary in order to keep up traffic. Another effect of this erosion becomes manifest wherever the streams reach flatter country. The sand resulting from this erosion, especially in granite country, is carried downwards into the waterholes, and is obliterating one after the other. So that, whether the river flow is rapid or slow, the waterholes have to disappear—either by draining or silting. From the angler's point of view, this is particularly sad, as these water holes once provided fine fishing. About Amphitheatre and Avoca, mining operations are popularly blamed for the silting, and no doubt these have had an appreciable effect, but the filling and draining of the water holes were inevitable in any case.

Clearing of the Forest Covering.

Above the junction of the Avoca, with its western tributary, the Amphitheatre or Glenlogie Creek, the area drained by the two systems is about 42 square miles, of which 23 square miles is drained by the Avoca River. Standing on the Sugarloaf, a peak about 1700 feet high between the two drainage areas, a good view of both is obtained. To the eastward lies the Avoca Valley, and to westward that of the Glenlogie Creek. The former was once the site of a large pastoral property, the Amphitheatre station. Though a true basin, and the country not very hilly, it does not seem suited for extensive cereal agriculture. There are, however, many flourishing apple orchards. It is a typical pastoral area, pleasant to look upon, and dotted over with well foliaged trees, mainly Eucalypts. These are apparently retained for shade purposes, and although unusually numerous for those, are not numerous enough to constitute forest. Most of the basin has been in its present state for perhaps 20 or 30 years, but within the last decade much clearing has been done on the slopes of Mt. Lonarch and Ben More, as well as on the Sugarloaf itself. On Mt. Lonarch the clearing is most noticeable, especially within the last five years, and amounts to perhaps two or three thousand acres.

Looking westward from the Sugarloaf over the Glenlogie Creek basin great alterations are apparent during the last five years, the forest country being now limited to a strip a mile or two in width running W.S.W., from the Amphitheatre township for about three miles along the southern side of the railway line, and it evidently will not be long before the firewood cutters will have cleared this area also. In that case the two basins will form one area practically cleared, except for the State forests, which cover the higher portions of the surrounding ranges, the Pyrenees to the north-westward, the Lonarch to the south, and Ben More to the east.

Effects upon the Permanence of the Streams.

It is common knowledge in that district that the clearing of the timber has most strikingly improved the summer flow of the streams, by increasing the activity and duration of the springs. It is within the writer's knowledge that the creek taking its rise in the granite hills south of "The Gap," the highest point on the road from Avoca to Ararat, and on the divide between the Avoca and Wimmera River basins, was, prior to 1881, dry for the greater part of each summer. Now it is a permanent stream, and even on April 19, 1922, was discharging perhaps five cubic feet per minute. The same applies to the Avoca and Glenlogie creeks at their junction below Amphitheatre, and both were running freely on the same date. It was of interest to note, too, that the two streams were there nearly equal, whereas prior to 1880 the Avoca was much the larger whether under flood or summer conditions. For this approach to equality, the cause is evidently the greater recent reduction in the forest covering of the Glenlogie Basin.

The deepening of the channels has had effects upon the extent of the flooding. According to Mr. Ennis, an Amphitheatre resident, the flats are now flooded less frequently and extensively than formerly. This is due in all probability to the increased channel capacity which also involves increased velocity. A proof of the latter was found by inspection of the Avoca branch, coarse sand and gravels generally being distributed very freely over the river flats and to an extent obviously very injurious to their pastoral usefulness. This was not the case formerly.

In response to my request, the Postmaster at Avoca submitted a number of queries to an old Avoca resident, Mr. Henry Brown, who kindly answered them very fully. His statements agreed very well with my impressions, except that he attributed the recent greater permanence of the river flow in summer to good spring rains and its occasional failures to the water carrying capacity of the underground drifts, which, if tested, he said, would show that the river never ceased flowing at all. Floods, he said, came down more rapidly than formerly, for which he blamed the silting up of the large waterholes by mining operations. Thousands of diggers had washed their dirt in the river, and the Golden Stream Gold Mining Coy. had run thousands of tons of "slum" from their puddlers into it. In places this slum in the bed of the river was 5 ft. thick. The floods were also heavier than previously, for which again he blamed the silting up by mining operations, causing lessened channel capacity. These siltings he also blamed for various changes in the course of the channel.

My observations of the changes in the country cover only a small part of the Avoca's drainage area, but it is probable that they apply with equal force to the whole area between the Avoca and the Pyrenees which provides the chief remainder of the effective drainage areas, or of a total of about 1000 square miles.

The flow of the Avoca River is officially measured by the State Rivers and Water Supply Commission at the Coonooer Weir, below

which the river gains only negligible additions. These records began in June, 1889. This weir appears to be the only interference with the flow of the Avoca River, the waters of which have never been seriously used for irrigation. The basin is, therefore, very suitable for such a study as the present one.

Summer and Minimum Flow Improving.

Inspection of the data published by the Water Commission shows a remarkable change in the constancy of the flow of the river. If we compare the records for the twenty years, 1890-1909 inclusive, with those for the ten years, 1910-1919, we find that in the former period the river actually had no flow or ceased to run in 79 months; that it, there were 79 months during the whole or a part of which there was no discharge at Coonooer Weir, or at all events nothing more than the leakage which does not exceed one-sixth of a cubic foot per second. During the decade 1910-19, the river has never ceased to flow, nor has it done so up to the end of 1921. A comparison of the two great drought years, 1902 and 1914, is equally instructive. Though the latter was the more severe the river flow never fell below 5 cubic feet per second, whereas in 1902 there were seven months during which the river never ran at all.

The following table shows the average minimum flow in cubic feet per second for all months for the twenty years, 1890-1909, and for the ten years, 1910-1919:—

	Jan.	Feb.	Mar.	Apl.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Avg
1890–1909.	1·4	0·65	1·0	1·2	1·8	7·3	16·1	24·7	18·1	10·7	6·0	3·0	7·6
1910-1919.	8·3	7·5	8·7	8·6	8·6	8·8	30·8	29·3	33·5	27·2	15·3	9·1	16·3

This shows that during the summer half of the year, November-April, the average minimum is now from *two to ten times* as great as formerly, and is also considerably greater during the winter half. That this is not due to any marked increase in the frequency of flood rains is shown from the records of Amphitheatre, Avoca, Stuart Mill, Emu and St. Arnaud. Taking all the occasions when the mean of the daily rainfalls at these stations has equalled or exceeded 50 points, or for two consecutive days 75 points, we get the following:—

	Jan.	Feb.	Mch.	Apl.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
1890–1909	6	5	13	16	16	26	16	10	10	10	9	8	145
1910–1919	2	8	7	4	9	12	10	7	11	5	3	7	85

Here the total "flood falls" for the summer halves are 57 for the former and 31 for the latter, and for the winter halves 88 and 54, showing clearly enough that it is not to any special increase in the

number of heavy rains the increased minimum flow of the river is due.

The Floods on the Avoca.

To estimate with any degree of accuracy the maximum volume of flood water likely to follow upon any rainfall seems almost impossible. We should need to know not only the amount of the rain for the day, but its intensities from hour to hour, the distribution in time and place of the heaviest showers, the degree of saturation of the soil, the amount of grass covering it, as well as the state of the river. Present data will not allow of these being weighed. Some generalised results may, however, be valuable.

As before mentioned, Amphitheatre, Avoca, Stuart Mill, Emu and St. Arnaud were the stations selected by me to provide the necessary daily rainfall data. These covered the effective drainage area very well. The rains necessary for flooding were reckoned, those of 50 points or more for one day, and 75 points or over for two days' rain. In the diagram these are shown graphically in spaces allotted for each month since 1889 along with the greatest volume in cubic feet per second, passing over the weir during each month.

During the 32 years with available records, the heaviest flood was in August, 1909, with probably well over 5000 c.ft. per second. Next came that of September, 1916, which was put at 5000 c.ft. Floods of 4000 c.ft. per second or over were reached in May, and in June, 1892, in September and October, 1893, in January, 1897, in March, 1910, in September, 1912, in September 1915, and in September, 1921.

The time distribution of all floods was as follows:—

c. ft. per sec.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Over 5000	—	—	—	—	—	—	—	1	1	—	—	—
4000–5000	1	—	1	—	1	1	—	1	5	1	—	—
3000–4000	—	1	—	—	2	6	3	5	11	2	2	—
2000–3000	—	—	—	1	—	6	4	3	1	—	—	—
1000–2000	—	—	—	—	1	1	7	8	3	4	2	—
	1	1	1	1	4	14	14	18	21	7	4	0

(1000 c.ft. per second would be given approximately by a stream 100 yds. wide and 1 ft. deep, flowing at a rate of 2 miles per hour.)

According to these figures floods are extremely unlikely to occur in the summer months, and they reach their maximum frequency and intensity in August and September.

The importance of the degree of soil saturation is made very obvious by the fact that the heaviest flood falls have not occurred in these months. The greatest of these was in March, 1910, when the mean for two days was $5\frac{1}{4}$ inches. The flood of January, 1897, was due to a fall of over 4 inches in one day. In February, 1911, a three-day fall gave 436 points. In April, 1890, 313 points fell on one day. In May, 1893, a fairly even five-day fall gave 5 inches. In July, 1903, 320 points fell in two days. The great flood of August, 1909, was due to a series

of thunderstorms giving a total fall of $3\frac{1}{2}$ inches in about 19 hours, with its heaviest downpours during the last hour over the head streams. The great flood of September, 1916, was due to 260 points falling in two days.

For the whole 32 years, 1890-1921, the number of rainfalls with flood possibilities (over 50 points for one day or 75 for two) were as follow:—January 9, February 13, March 20, April 20, May 27, June 43, July 28, August 21, September 25, October 15, November 14, December 15. These are very different from the actual numbers of floods occurring these months, except in August and September.

Flood Volumes Increasing.

Owing mainly to the variability in the dates on which the winter rains may be said to have begun, and the soil to become well moistened, the only months which show any approach to consistency in the relation between the rainfalls and resulting floods are July, August, and September. Taking an average of all the rains with flood possibilities, we get the following results for the earlier and later periods:—

—	July.			August.			September.		
	No.	Average Rainfall	Flood in cusecs.	No.	Average Rainfall	Flood in cusecs.	No.	Average Rainfall	Flood in cusecs.
1890–1909 - - -	13	103	1444	11	116	2135	10	114	1766
1910–1921 - - -	10	93	1641	9	110	2092	14	149	3564

So far as these results go, they show an improved run-off during the later period.

Flood Rains and Flood Volumes.

As already remarked, the run-off after any particular rainfall varies enormously and can only be guessed at with any probability of success when other conditions are known. For example, it is only the very exceptional rainfall which will cause serious flooding of the river during the six summer months, November to April. November can only show three floods in 32 years, a rainfall of 194 points, giving 3600 c.ft. in 1893, a rainfall of 277 points, giving 3850 c.ft. in 1903, and a rainfall of 166 points, giving 1900 c.ft. in 1906. In December there have been no floods. In January only one, a 411 points rain in one day, in 1897, giving a flood of 4100 c.ft., in February only one, a three-day fall of 430 points giving a flood of 3850 c.ft. in 1911; in March only one, a three-day fall of 552 points, giving a flood of 4000 c.ft. in 1910; in April only one, a fall of 313 points in 1890, giving a flood of 3500 c.ft. The comparative rareity of floods in May and October is probably also due to the liability of the soil to be dry in those months. In the case of the former, because the dry season is usually scarcely over; in the case of the latter, because growing vegetation is making

great demands upon the soil moisture, as well as obstructing the flow of water down the slopes of the drainage area.

Flood Prediction.

As the months of June, July, August and September are obviously the flood months, it may be worth while giving in tabular form some average results based upon the whole 32 years' record. All Junes and Julys preceded by months with less than 2 inches of rain are excluded. The flood rains are grouped as follow:—under 1 inch, from 1 inch to 149 points, from 150 points upwards. While the variation is great for all months, that for June is particularly so.

Month.	Rainfalls under 100 points.			Rainfalls of 100 to 149 points.			Rainfalls of 150 points and over.		
	Average amount.	No.	Flood volume in cusecs.	Average amount.	No.	Flood volumes in cusecs.	Average amount.	No.	Flood volumes in cusecs.
June - -	76 pts.	6	600	126 pts.	6	2190	170 pts.	6	2500
July - -	80 pts.	12	1400	129 pts.	5	1870	235 pts.	2	3600
August -	83 pts.	8	1740	122 pts.	6	2340	230 pts.	3	3970
Sept. -	87 pts.	7	1460	125 pts.	7	3160	196 pts.	9	3590

Annual Run-off Increasing.

That the volume as well as constancy of the flow of the Avoca River over the Coonooer Weir is increasing greatly is shown decisively by the official gaugings. As previously remarked, so many factors powerfully affect the run-off that unless the chief of these are known it is hopeless to attempt to estimate the flood height from any particular rainfall. But by taking a sufficiently long period it may be assumed that average results will provide data for reasonably reliable deductions. The official guagings cover 32 years. These provide three decades, exclusive of the years 1920 and 1921. The first of these, 1890-1899, was the wettest, giving an average of 20·1 inches annual rainfall, and an average annual run-off of 59,278 acre feet. The next decade had an average rainfall of 19·4 inches, and a run-off of 44,230 acre feet. The last decade 1910-1919, had a rainfall of 19:5 inches, and a run-off of 74,439 acre feet. Taking a mean of the first two, we get an average run-off of 51,700 acre feet for a rainfall of 19:7 inches. As the average rainfall for the last decade was 0:2 inches less, and the average run-off 22,700 acre feet more, there seems no reason to doubt that the run-off is increasing. This is made even more emphatic by taking in the years 1920 and 1921, with rainfalls of 19 and 22 inches respectively, and run-off totals of 94,909 and 93,155 acre feet. These make for the last 12 years the average run-off 77,700 acre feet, for an average rainfall of 19:7 inches. The rainfall therefore averages out the same as for the previous 20 years, but the run-off has increased by 26,000 acre feet, or by over 50 per cent. (The rainfall data here used are those published by the Water Commission.)

The improvement in the run-off may be made more obvious perhaps if we limit the comparison periods to the winter months and begin each flood season only with those months prior to which sufficient rain has fallen to make the soil fairly moist. This will require, say, two inches of rain during the preceding month. This means that the period will rarely begin before May and will end not later than October. Adopting this procedure and using the rainfall data from the five stations selected by myself, which are slightly wetter than the average for the basin, the following results were obtained.

The years 1890 to 1909, omitting the great drought year, 1902, gave a total of 102 months with an average rainfall of 2:53 inches, and average mean monthly river flow, of 152 c.ft. per second. The years 1910 to 1921, omitting the drought years 1914 and 1919, gave 50 months, with an average rainfall of 2:75 inches, and average river flow of 270 c.ft. per second. That is, unless the run-off has improved, an increase of 22 points in the rainfall gives an increased run-off of 118 c.ft. per second, or a 10 per cent. rainfall increase means a 60 per cent. run-off increase, which seems hardly possible.

In order to get a series of earlier years with approximately the same rainfall as that of the later series, it will be necessary to reject, in addition to 1902, the rather dry years, 1895, 1896, 1897, 1899, 1904, and 1907. The remaining 13 years give an average monthly rainfall of 273 points, and an average mean river flow of 187 c.ft. per second. Therefore, for practically the same rainfall we get an increase in the run-off of nearly 45 per cent.

The very wet months in these periods, or of over 4 inches, were as follow:—

1890, June, 431 pts.	1909, August, 695 pts.
1893, May, 660; June, 485 pts.	1911, September, 406 pts.
1894. October, 605 pts.	1912, September, 536 pts.
1898, June, 520 pts.	1915, Sept., 547; June, 419 pts.
1899, June, 456 pts.	1916, June, 410; Sept., 457 pts.
1900, August, 403 pts.	1920, August, 505 pts.
1906, May, 448; June, 438 pts.	1921, September, 44 pts.
1903, July, 481, and Sept., 409 pts.	

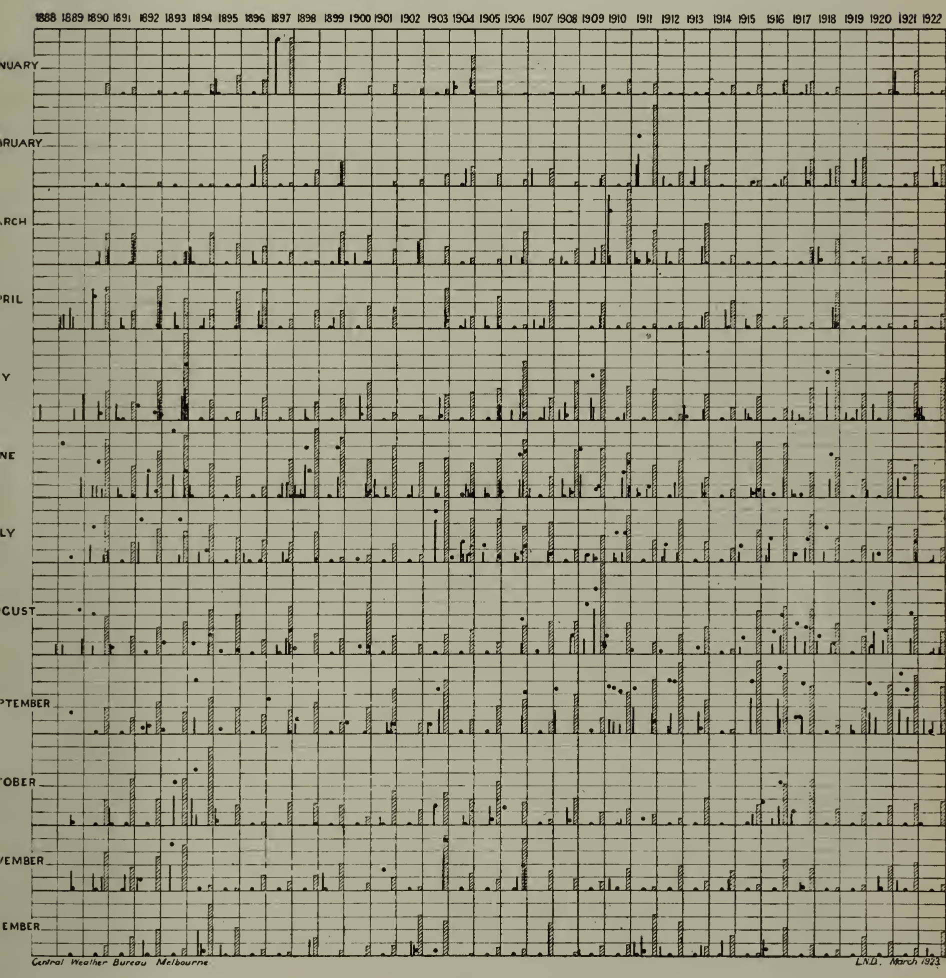
This gives 12 for the 20 earlier years, with an average of 503 pts., and 8 for the later 12-year period, averaging 466 pts.; which rather favours the earlier period as regards flood possibilities.

This 45 or 50 per cent. gain may be apportioned to the two main sources of increased flow, (a) the amount gained by springs from the destruction of the trees, and given to maintain a constant flow; (b) the increased run-off due to the better drainage resulting from erosion of channels, silting up of water holes, formation of paths by stock, moister condition of subsoil, quicker saturation of the subsoil due to killing of the trees, the raising of the water table, etc. It has already been shown that the former results in an average increased minimum flow of 8:7 c.ft. per second. This gives for one year, 6300 acre feet. That leaves, therefore, as the gain due to the second group of causes about 20,000 acre feet.

All the information available goes to show that the changes described for the Avoca River basin are common to all our inland drainages. If so, the results must be of the utmost importance. Our inland water supplies may be increased greatly, and if properly utilised may produce effects, climatic included, beneficial beyond anything we have yet ventured to anticipate.

The bearing of this upon the filling of our inland lakes, such as Torrens and Frome, and the resulting climatic improvement is obvious.

Graph showing for the Avoca River basin: (a) the flood rains; (b) the resulting flood volumes; (c) the total rainfall for the month.



Each vertical space represents, in the case of rainfall, one inch; in the case of flood volume, 1000 cubic feet per second. The rainfalls are indicated by vertical lines and hatched columns, the flood height by the position on the vertical scale of the round dots. For (a) and (b) the dates of occurrence are indicated by their position on the horizontal scale.